Renewable and Sustainable Energy Reviews 13 (2009) 1275–1287

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Biofuels: Environment, technology and food security

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ARTICLE INFO

Article history:
Received 30 May 2008
Accepted 9 August 2008

Keywords:
Biofuel production
Environment
Technology
Food security

ABSTRACT

The imminent decline of the world's oil production, its high market prices and environmental impacts have made the production of biofuels to reach unprecedent volumes over the last 10 years. This is why there have been intense debates among international organizations and political leaders in order to discuss the impacts of the biofuel use intensification.

Besides assessing the causes of the rise in the demand and production of biofuels, this paper also shows the state of the art of their world's current production. It is also discussed different vegetable raw materials sources and technological paths to produce biofuels, as well as issues regarding production cost and the relation of their economic feasibility with oil international prices. The environmental impacts of programs that encourage biofuel production, farmland land requirements and the impacts on food production are also discussed, considering the life cycle analysis (LCA) as a tool.

It is concluded that the rise in the use of biofuels is inevitable and that international cooperation, regulations and certification mechanisms must be established regarding the use of land, the mitigation of environmental and social impacts caused by biofuel production. It is also mandatory to establish appropriate working conditions and decent remuneration for workers of the biofuels production chain.
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Contents

1. Introduction . . . 1276
2. Factors that influence the manufacture and the use of biofuels in the world . . . 1276
   2.1. Current panorama of the oil reserves in the world . . . 1276
   2.2. Climatic changes . . . 1276
   2.3. Biofuels . . . 1276
   2.4. Raw materials for the synthesis of bio-ethanol . . . 1278
   2.5. Raw materials to obtain biodiesel . . . 1278
   2.6. State-of-the-art and prognoses regarding the use of biofuels in the world . . . 1278
   2.7. Necessary farmland for biofuels . . . 1279
   2.8. Technologies for the attainment of biofuels . . . 1279
   2.9. First generation routes (production of biodiesel and ethanol through conventional ways) . . . 1279
   2.10. Second generation routes (products from pyrolysis/gasification syngas, cellulosic ethanol through hydrolisis, etc.) . . . 1280
   2.11. Biofuels production cost . . . 1281
   2.12. Biofuels and the environment . . . 1282
   2.13. Biofuels and food security . . . 1283
3. Conclusions . . . 1285
   Acknowledgements . . . 1286
   References . . . 1286

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doi:10.1016/j.rser.2008.08.014

1. Introduction

Today, mankind is facing as once did the mythological Orestes—the harassment of three Furies or Erenias: hunger, the lack of energy and the deterioration of the environment.

The point is that it is mandatory to defeat all these three Furies simultaneously, because any one of them, by itself, is able to wipe out our civilization. Today, for the first time in history, the human race may be the victim of its own genius. Talking about energy, when we think about the whole problem, it is evident to everyone that saving it is the strategic approach to be privileged by reducing the enormous and irrational levels of consumption and increasing the efficiency of the use of conventional fuels, because it gives the best cost/benefit relation; but it is important not to forget the need to find new fuel sources.

Fossil fuels account for over 80.3% of the primary energy consumed in the world, and 57.7% of that amount is used in the transport sector [1]. This way, it is possible to conclude that fossil fuels are responsible for the emission of a significant amount of pollutants in the atmosphere, including greenhouse gases (GHG).

The intensive and low-efficient use of fossil fuels for supplying humans' energy needs over the past century reduced its reserves considerably, resulting in the prognosis of its exhaustion within the next decades. This phenomenon, known as 'Peak-Oil', will probably be characterized by the reduction in the world's oil production that may already start in 2010. This situation is causing a rise in the prices, bellicose conflicts, making some governments considerably concerned towards assuring their energy security. There is a unanimous opinion that says that the era of cheap energy is long gone.

Climatic changes, as a result of global warming caused by greenhouse gases, mainly carbon dioxide (CO_2) produced during the burning of fossil fuels, have been causing significant changes in the ecosystems and leading to nearly 150,000 additional deaths every year [2]. The constant rise in Earth's average temperature, threatens millions of people with the growing risk of hunger, floods, water shortage and diseases such as malaria.

Taking the aforementioned problems into account, the use of biomass, particularly biofuels, for energy purposes becomes increasingly interesting.

As a general conception biofuels are products that can be used for powering internal combustion engines. Obtained from natural sources, they are renewable and can recycle the CO_2 from their combustion through photosynthetic ways.

They can be direct and immediate replacements for the liquid fuels used in transport and can be easily integrated to the logistic systems that are operating today.

Replacing a percentage of gasoline and diesel, for example, for biofuels (biodiesel or bio-ethanol) is the simplest way to increase the availability of the fuels in the transport sector [3]. The efficient use of the resources involved in the biodiesel and ethanol-producing chain is an indispensable aspect to be studied, which deserves as much attention as the development of alternative fuels.

Given the large extensions of land demanded to grow biofuels crops, the assessment of the impacts that extensive biofuel production programs may cause to food supply and to the environment has considerable importance.

2. Factors that influence the manufacture and the use of biofuels in the world

2.1. Current panorama of the oil reserves in the world

The world's oil reserves are distributed extremely irregularly. Only some areas have exceptional geological features that allowed the formation and the accumulation of significant amounts of oil. The Middle East concentrates about 65% of the world's reserves, whereas Europe and Eurasia have 11.7%, Africa 9.5%, Central and South America 8.6%, North America 5%, and Asia and the Pacific 3.4% [4] (Fig. 1).

A recent study [5] presents the projection of the world energy demand for the near future (Fig. 2). This study shows the imminent reduction in the world's fossil fuel production and the need to use new energy sources that can contribute to meet towards meeting the demands.

2.2. Climatic changes

Climate changes take place as a result of the intrinsic variability of climatic systems and of the action of external factors, either natural or anthropogenic. The emissions of greenhouse gases tend to elevate the temperature of the planet excessively. The temperature rise reached 0.6% with forecasts ranging from 2 to 4 °C by the end of this century. The report of the 4th Intergovernmental Panel on Climate Change—IPCC recognizes as highly confidence that the global warming is the net result of human activities [6].

One of the most important greenhouse gases is the CO_2. Over the past century, the atmospheric concentration of CO_2 reached its highest levels, as it is possible to be observed in Fig. 3 [7]. Since the pre-industrial times, the atmospheric concentrations of greenhouse gases have been increasing as a consequence, which has been just recognized, of human activities. This rise is mainly caused by the unsustainable use of fossil fuels and the changes in the use of the land (IPCC [56]).

The expected variation regarding the climate includes changes in the intensity and in the distribution of rainfall, the elevation of the level of the oceans and a growing increase in the frequency and intensity of extreme climatic phenomena.

According to IPCC [8] the biofuel demand for the transport sector in 2030 is forecast to be 45–85 EJ, based on primary biomass, or 30–50 EJ based on fuels. The same source indicates a global potential regarding the energy supply of biomass of 125–760 EJ in the year of 2050. This makes the energy use of biomass, in its different variants, a subject to be considered as an important element towards the mitigation of the greenhouse effect.

The use of biofuels in internal combustion engines is not recent. In 1900 the inventor of the diesel engine, Rudolf Diesel, forecast the possibility of using vegetal oil, such as peanut oil, in his engines.

Indeed, vegetal oil was used as fuel, either pure or blended, but there were technical problems that prevented its widespread use. The greatest difficulty was the formation of residues, which reduced the power of the engines and demanded frequent stops to clean and unblock the fuel injectors. In 1937, the vegetal oil transesterification process was patented. This process breaks the oil molecules, blends the fatty acids with alcohol and separates the glycerin, the cause of the deposits in the engines [9].

In relation to ethanol, this was the fuel initially intended for the first Otto Cycle engines, developed at the early years of the automotive industry [3]. The development of oil derivatives, with a wide offer of different fuels at low prices, made these alternatives uninteresting. In the late 1920s, the former Experimental Station on Fuels and Minerals, currently the National Institute of Technology—NIT, carried out some tests using alcohol in a 4 cylinder Ford [10], aiming at promoting alcohol as an attractive energy alternative.

Today, many of the technical difficulties caused by the burning of biofuels in internal combustion engines, which appeared in the initial attempts to use this type of fuel, have been solved. This makes the alternative of using these fuels a feasible one for the partial replacement of fossil fuels in the transport sector.

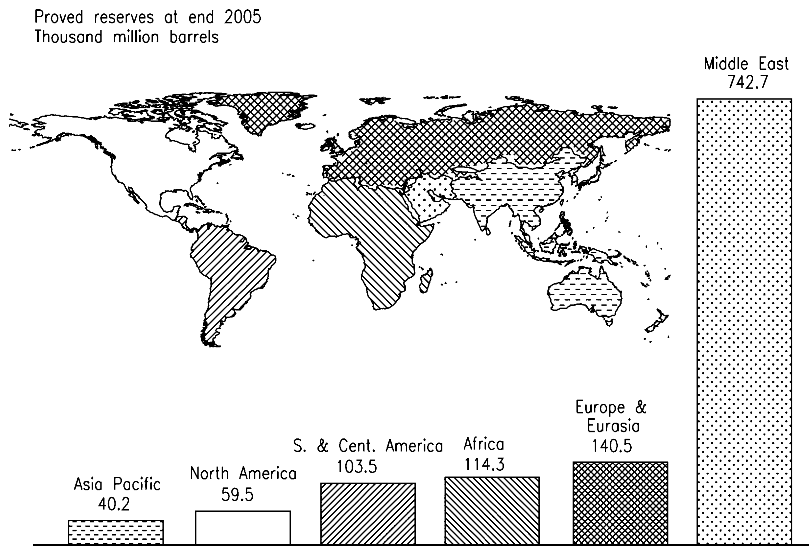

Fig. 1. Current panorama and distribution of the oil reserves in the world [4].

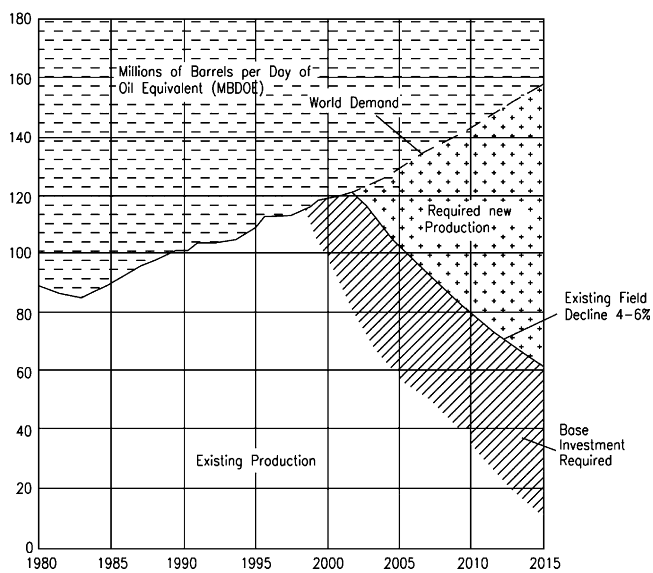

Fig. 2. Projection of the energy demand for the next years [5].

2.3. Biofuels

Biofuels are renewable and they come from agricultural products such as sugarcane, oleaginous plants, forest biomass and other sources of organic matter. They can be used either isolated or added to conventional fuels in blends. As examples, it is possible to mention biodiesel, ethanol, methanol, methane and charcoal.

According to the American Society of Testing and Materials (ASTM) biodiesel is technically defined as: a fuel composed of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats [11].

The international practice led to the adoption of a single nomenclature to identify the concentration of biodiesel in the blends, known as the BXX nomenclature, where the XX is the percentage in volume of the biodiesel in the diesel/biodiesel blend. For example, B2, B5, B20 and B100 are fuels with a concentration of 2%, 5%, 20% and 100% of biodiesel, respectively.

Nowadays, there are four main concentrations of biodiesel being used in the fuel market:

√ Pure (B100).
√ Blends (B20–B30).
√ Additive (B5).
√ Lubricity additive (B2).

The blends in volumetric proportions between 5% and 20% are the most common. The B5 blend does not require any modification in the engines. Biodiesel is perfectly miscible and also physically and chemically similar to mineral diesel, and can be used in compression ignition engines without significant or onerous adjustments.

Bio-ethanol is defined by the US DOE [12] as an alternative fuel based on alcohol, produced by the fermentation and distillation of raw materials with high content of sugars and starch. Besides these raw materials, ethanol can be obtained out of ligno-cellulosic biomass from trees and some herbs.

Any amount of ethanol can be blended with gasoline [13]. However, the most common blends are E10 and E85, which contain a concentration of 10% and 85% of ethanol, respectively. 100% of

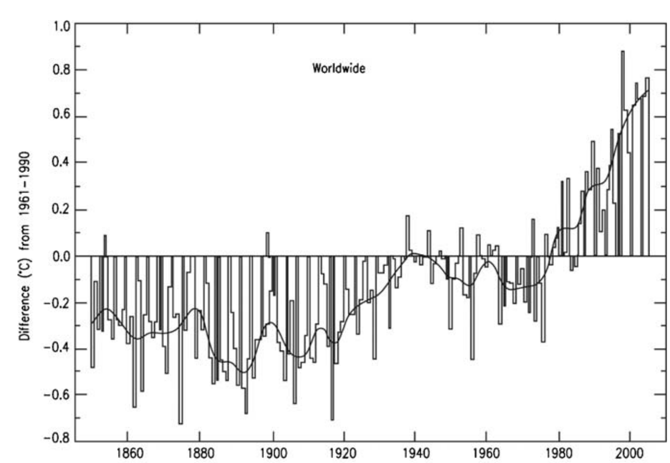

Fig. 3. Variations in the concentration of CO_2 in the atmosphere and the rise in the planet's global temperature [6].

Table 1
Preliminary agro-climatic requirements of some raw plants materials for the attainment of biofuels [52,53,55].

Type of crop	Soil	Water	Nutrients	Climate
Corn	Well-aerated and well-drained soil	Efficient use of water	High fertility	Tropical conditions
Palm oil	Good draining, pH between 4 and 7, flat, rich and deep surface	Uniform amount of rain: between 1800 and 5000 mm a year	Low	Tropical and subtropical with temperatures between 25 and 32 °C
Rapeseed	Soft. Muddy, average texture, well-drained	Minimum precipitation of 600 mm a year	High	Sensitive to high temperatures, it grows best between 15 and 20 °C
Soybean	Aluvian soil with a good amount of organic content, a high water capacity and a good structure	High	Optimum pH from 6 to 6.5	Tropical, subtropical and moderate climates
Sugarbeet	From medium to low heavy texture, good draining, salinity tolerant	Moderate, ranging between 550 and 750 mm of rainfall during the growth period	High fertilizer demand. Appropriate amounts of nitrogen	Variety of moderate climates
Sugarcane	Preferable well-aired with a good amount of water (15% or more)	High precipitation equally along the seasons	High amount of nitrogen and potassium	Tropical and subtropical
Wheat	Average texture	High	High	Moderate climates: in subtropic areas with rainy winters and in tropic areas on mountainous regions
Castor	pH between 5.0 and 6.5	At least 400 mm of rainfall in the seedling and blossoming periods	Reasonable demand for essential nutrients, especially nitrogen, potassium, phosphorus, calcium and magnesium	Tropical with temperatures ranging from 20 to 30 °C
Physic nut (Jatropha curcas)	Semi-arid soil	At least 400 mm of rainfall along the year	Low	Average temperature above 20 °C (with a limit of 28 °C)

ethanol can be used as automotive fuel, but the blends between 25 and 85% can only be used by dual-fuel automobiles.

Today, the ethanol is used as fuel mainly in Brazil, and as additive to increase gasoline octane number in countries such as the United States, Canada and India [14].

2.4. Raw materials for the synthesis of bio-ethanol

Ethanol can be produced out of any organic matter of biological origin that has considerable amounts of sugars and materials that can be converted into sugar such as starch or cellulose. Sugarcane, sugar beetroot, sugar sorghum are examples of raw material that contain sugar and, therefore, can be used for ethanol production. Wheat, barley, corn are also raw materials that contain starch, which can easily be converted into sugar by using the available technologies. A significant part of the wood of trees and herbs is composed by cellulose, which can also be converted into sugar, but the process is more complicated than the one required for starch.

2.5. Raw materials to obtain biodiesel

Basically, biodiesel can be attained from oils and fat that come from:

- oleaginous plants: castor, African palm (known in brazil as dendezeiro), soybean, rapeseed, sunflower, physic nut (jatropha curcas), thistle seeds, etc.;
- used vegetal oils: they come from restaurants and hotel industries and households;
- animal fat: it comes from slaughterhouses.

It is observed that the production of biofuels is mainly based on agriculture raw material and, therefore, many countries can easily produce them attaining several benefits such as a greater energy security, diversification of energy sources and agriculture, accelerated development of rural areas with the consequent increase in job opportunities in these areas. In addition, the countries that produce a large amount of biomass are not usually fossil fuel producing countries. Consequently, new countries will enter in the global energy market, which would reduce the world's dependence on the few countries that have oil reserves.

It is important to observe that not all the countries comprise the climatic, topographic, edaphic, and other conditions that are necessary for the large-scale biofuel production, given that the economic feasibility of these fuels depends on the crops used for their attainment and the efficiency of their processing—refer to Table 1 [15,16].

2.6. State-of-the-art and prognoses regarding the use of biofuels in the world

Considering the reasons presented in the previous items, it is possible to observe, at a worldwide level, a tendency towards a rise in the production of biofuels, which can lead to the supposition of an equally growing market demand. Figs. 4 and 5 present the behavior of the biofuel world production within the period between 1991 and 2005 for biodiesel, and 1975 and 2005 for bio-ethanol. Within the period between the years of 2000 and 2005 one can observe a higher increase in the production of biofuels, with the production of biodiesel going from 893 to 3762 million liters and the production of ethanol from 17.3 to 44.8 billion liters [17].

Table 2 shows the five largest ethanol and biodiesel world producers and the main raw materials used for manufacturing these fuels.

It also shows that nearly all of the commercial production of biodiesel takes place in Europe, where Germany, France and Italy are the main producers. European countries produce more biodiesel than fuel ethanol, but the total production of both fuels can be considered small if compared to the ethanol production of countries such as Brazil and the USA.

According to data provided by IEA [18] it is expected that the participation of biofuels in the transport sector goes up from today's 1% to values close to 7%, in 2030. This represents a rise equivalent to 15.5 Mtoe (Million of tones of oil equivalent), in 2004, to 146.7 Mtoe, in 2030. The highest rise in biofuel consumption will take place in the United States, Europe, Asia and Brazil. The rise in consumption in the other regions will be modest.

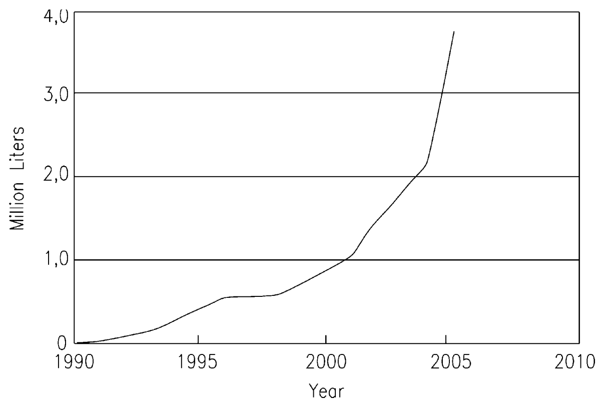

Fig. 4. Biodiesel world production between 1991 and 2005 [17].

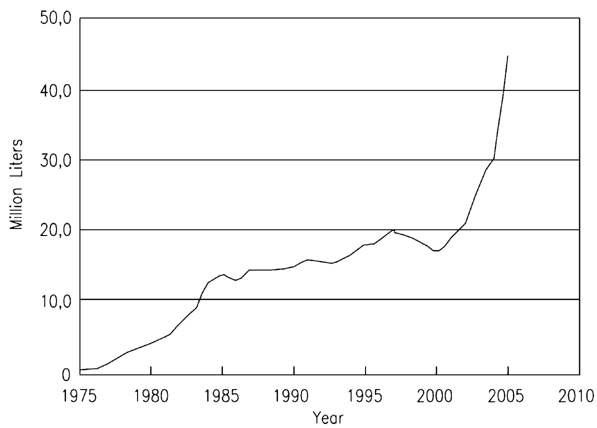

Fig. 5. Ethanol world production between 1975 and 2005 [17].

2.7. Necessary farmland for biofuels

According to FAO [19] the amount of land used for worldwide agriculture and food production is approximately 1500 million hectares, which represents 11% of the earth's surface. In addition, 2800 million hectares have the potential to be used. However, part of this surface is not available or it is destined to other uses. Nearly 45% is covered by woods or forests, 12% correspond to protected areas and 3% is occupied by human settlements. Latin America, the Caribbean and Sub-Saharan Africa have the largest lengths of available land surfaces.

Today about 14 million hectares of farmland are being used for the production of biofuels, which represent approximately 1% of the entire cultivated land in the world [18].

Ethanol is expected to be the greatest responsible for the growth in the use of biofuels all over the world, because its production costs must go down faster than the costs of biodiesel. It is also possible to observe that the commerce of biofuels is increasing, but their contribution towards the world energy supply continues to be small [18].

Table 3 presents a prognosis regarding the consumption of biofuels in the transport sector in different regions of the world.

According to the scenarios of land occupation, projected by the International Energy Agency [20] for the USA and Europe, it was possible to observe that in the short run the goal to replace 6% of oil derivatives for biofuels is compatible with today's available amount of land. In order to replace 5% of gasoline, the European Union would need approximately 5% of the total amount of farmland, whereas the USA would need 8%. As far as the replacement of diesel is concerned, the demand of land is higher, mainly because the average yield of the raw materials used for manufacturing biodiesel is lower than in the case of bio-ethanol (Fig. 6). In this scenario, the USA would need 13% of their available farmland to replace 5% of the diesel used in transportation, whereas Europe would need 15%.

In the case of Brazil, the sugarcane crops occupy today an area of 6.2 million hectares. Other 200 million hectares correspond to pastures. A productivity gain of 20% in the use of pasture lands would make 40 million hectares available for the expansion of sugarcane crops. In order to meet the demand in case the entire world decides to add 5% of alcohol to gasoline, a little over 10 million hectares would be necessary [21]. Some oleaginous plants such as castor can be grown in degraded land, contributing towards the development of those regions. It is also observed a tendency towards the substitution of areas destined to soybean crops and pastures for sugarcane crops, with the impending danger of the first to start occupying areas that belong to the Amazon forest.

Another important aspect regarding the raw material cultivation and production of biofuels is the energy yield (GJ/ha), which could be expressed also in terms of tones of oil equivalent per hectare. These indexes allow the attainment of references in relation to the replacement potential of a given fossil fuel (toe/ha), as well as the possibility of expansion of each one of the raw materials used nowadays. Table 4 presents the average or a typical range of values concerning the production of biofuels per ha (GJ/ha) and the corresponding need of land (ha/toe).

2.8. Technologies for the attainment of biofuels

Technological routes.

The technological routes towards the manufacture of biofuels are usually classified by the experts into: first, second and third generation.

2.9. First generation routes (production of biodiesel and ethanol through conventional ways)

The biodiesel attained out of oil produced from oleaginous plants uses transesterification processes or cracking to convert the vegetal oils into a fuel that can be used by engines. Vegetable oils can be also used directly as fuels in specially designed or modified engines.

Table 2
Main ethanol and biodiesel producers in 2005 [49].

Bio-ethanol			Biodiesel		
Country	Million of liters	Raw material	Country	Million of liters	Raw material
Brazil	16,489	Sugarcane	Germany	1919	Rapeseed
USA	16,217	Corn	France	511	Soybean
China	1,998	Corn and wheat	USA	291	Rapeseed
E.U.	950	Sugar beet, wheat and sorghum	Italy	227	Rapeseed
India	299	Sugarcane	Austria	83	Rapeseed

Table 3
Projection regarding biofuel consumption in the transport sector [18].

	2004		2030	
	Demand (Mtoe)	% Highway transportation	Demand (Mtoe)	% Highway transportation
OCDE	8.9	0.9	84.2	7.2
North America	7.0	1.1	45.7	6.4
The USA	6.8	1.3	42.9	7.3
Europe	2.0	0.7	35.6	11.8
Pacific Islands	0.0	0.0	2.9	1.9
Transition economics	0.0	0.0	0.5	0.6
Developed Countries	6.5	1.5	62.0	6.9
China	0.0	0.0	13.0	4.5
India	0.0	0.0	4.5	8.0
Other Asian Developed Countries	0.1	0.0	21.5	4.6
Brazil	6.4	13.7	23.0	30.2
World	15.5	1.0	146.7	6.8
European Union	2.0	0.7	35.6	11.8

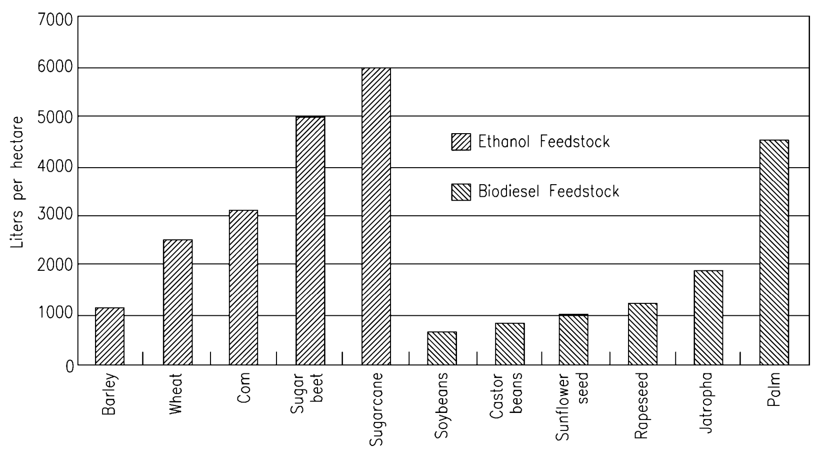

Fig. 6. Yield per hectare of different raw materials use for the attainment of bio-ethanol and biodiesel [49].

Transesterification can use alkaline, acid or enzymatic catalyzers, and ethanol or methanol, and produces fatty acid and glycerin as residues.

Bio-ethanol, produced out of organic based matter with high contents of sugars, is usually attained through fermentation. Initially the raw materials are submitted to a process where its sugar is separated. The fermentation processes use yeast to convert the glucose into ethanol. The distillation and the dehydration are used as the last steps for reaching the desired concentration: hydrated or anhydrous ethanol, which can be blended with gasoline or directly used as fuel in dual-fuel vehicles.

When the used raw materials are grains, usually hydrolysis is used for converting the starches into glucose. Given that converting starch into glucose is much easier than converting cellulose, the production of ethanol in the USA is mainly based on wheat and corn, and wheat, barley, and sugar beetroot in Europe [20]. The conventional processes used for attaining ethanol out of grains only use the part that contains starch. In this case, only the germ of the corn and of the barley are used, and that represents a small percentage of the total mass of the plant, generating a significant amount of fiber residue.

Considering that corn and other starch raw materials used for the attainment of sugars are a small fraction of the biomass that can be used to produce ethanol, it is necessary to develop technologies that allow the use of new sources of raw materials such as cellulosic biomass from vegetal fibers that are present in agricultural and forestry activities residues, trees and bushes, resulting in a higher efficiency than the first generation technologies.

Table 4
Production of biofuels per ha (GJ/ha) and the corresponding need of land (ha/toe) (Girard and Fallot [57] and Yañez et al. [54]).

Generation	Biofuels	GJ/ha	ha/toe
1°	Sunflower biodiesel	36	1.17
	Soybean biodiesel	18–25	2.35–1.67
	Wheat ethanol	53–84	0.79–0.50
	Corn ethanol	63–76	0.66–0.55
	Sugar beet ethanol	117	0.36
	Sugarcane ethanol	110–140	0.38–0.30
	Palm oil	158.4	0.285
2°	Switchgrass ethanol	228–407 (future)	0.18–0.10
	FT biodiesel—eucalyptus crop	460–620	0.08
	Eucalyptus crop—methanol	800–1000	0.04
	Eucalyptus crop—DME	850–1100	0.04

2.10. Second generation routes (products from pyrolysis/gasification syngas, cellulosic ethanol through hydrolisis, etc.)

In this case, the biofuels can be obtained through the following processes:

√ Cellulose hydrolysis followed by sugars fermentation. Cellulose and hemicelluloses, which are the building materials of the structure of the plants, are their two main components. They can be converted into sugars (C6 and C5) and, thus, it is possible to attain ethanol out of them.
√ Pyrolysis of biological matter composed mainly of cellulose, proteins and/or oils for the attainment of 'bio-oil' and char that can be used as a diesel blend or a substitute or gasified.

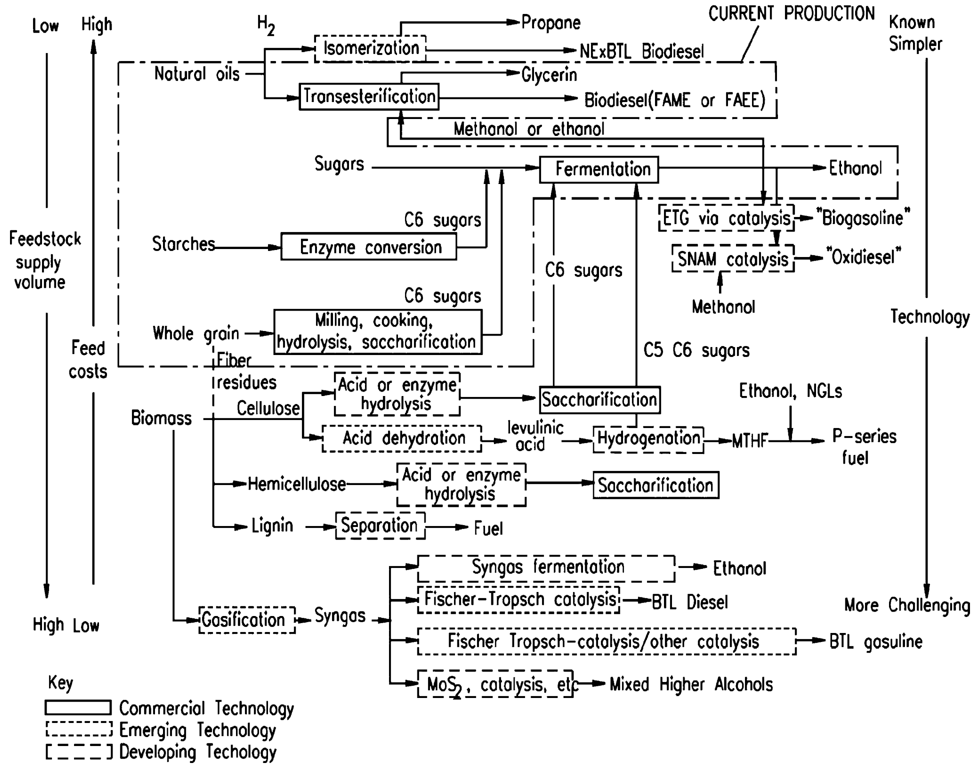

Fig. 7. Technological routes for the production of biofuels [50].

- √ Gasification of different biological matter for the production of synthesis gas or syngas, which allows the attainment of liquid biofuels through several catalytic processes. Today, this technology is going through the development and commercialization phase, including: Fischer-Tropsch technology (BTL) for the production of biodiesel or biogasoline through of the syngas conversion, technologies for the attainment of bio-ethanol with a high content of alcohols and blended alcohols as gasoline blend or substitutes and technologies developed to ferment the syngas to ethanol having hydrogen as by-product.
- √ Anaerobic digestion of the cellulose from agricultural residues or crops for the attainment of methane or it upgrade to synthetic natural gas.

The bio-H_2 is considered by some authors as a third generation fuel.

None of the second generation route biofuels are commercially available, given that the production costs are still prohibitive. These technologies are expected to achieve industrial scale within the next few years.

Fig. 7 presents the current development state of the technological routes regarding the attainment of biofuels.

The main advantage of the production of biofuels through the second generation technological routes lies on the fact that they allow the use of inedible raw materials. Many of them are considered to be residues and, therefore do not compete with food production. Also, their available volume is much higher.

2.11. Biofuels production cost

As far as biodiesel is concerned, its cost depends mainly on the raw material that is used for its production [22]. The biodiesel attained out of animal fat and recycled cooking oil has a lower price in relation to the one produced out of vegetal oils such as soybeans and colza. In fact, it has a lower cost than the fossil diesel. Fig. 8 shows a comparison between the biodiesel production costs for different raw materials used in the USA and Europe and the fossil diesel.

Today, the attainment of ethanol out of ligno-cellulosic material is not economically feasible on an industrial scale [23]. Within the next few years, the solution for this problem will lies on determining the best option to attain the glucose through cellulose hydrolysis in terms of global cost, glucose yield and fermentability of the hydrolized matter [24].

Fig. 9 presents values of the production cost ranges of ethanol and gasoline in the year of 2006.

The oil cost directly influence the economic feasibility of the biofuels. Thus, as far as the international cost of the oil keeps rising, the profitability from the production of biodiesel and bio-ethanol out of different raw materials will be much higher.

In order to determine the price of oil in the world market, which is the starting point from which the production of biofuels becomes profitable, an indicator known as break even point (balance point) is used. In the European Union the break even point for different biofuels can be reached from US$ 75 to 80/barrel of oil in relation to colza oil, US$ 90/barrel in relation to bio-ethanol, US$ 100/barrel to biodiesel and US$ 155–160/barrel to fuels attained by considering second generation technologies [25].

In the USA the break even point for bio-ethanol corresponds to oil prices ranging from US$ 40 to 50/barrel. This means that its production is unfavored with prices below US$ 40/barrel" [26].

In the case of Brazil, the break even point oscillates between US$ 30 and 35/barrel, when ethanol is considered. For biofuels derived from vegetal oils, given that this technology is still incipient, this indicator is estimated to be in the range about US$ 60/barrel [27].

The need to reduce the production cost of biofuels within the next few years is remarkable, given that today, their prices greatly depend on subsidies implemented by the governments.

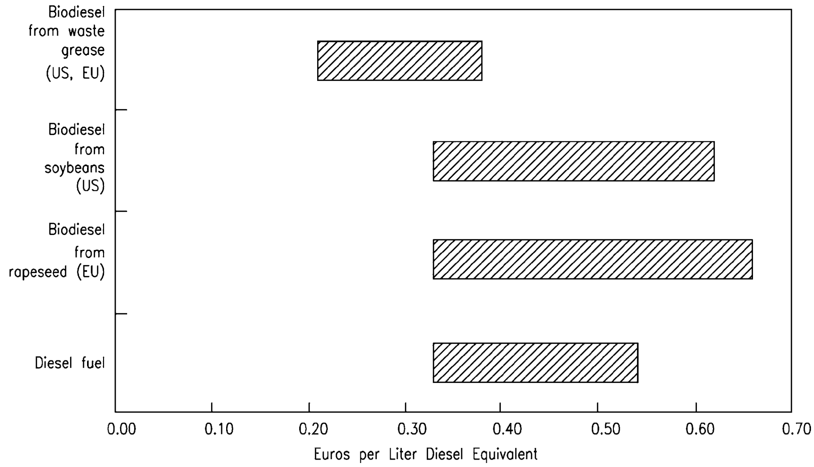

Fig. 8. Range of production costs for biodiesel and diesel in the year of 2006 [51].

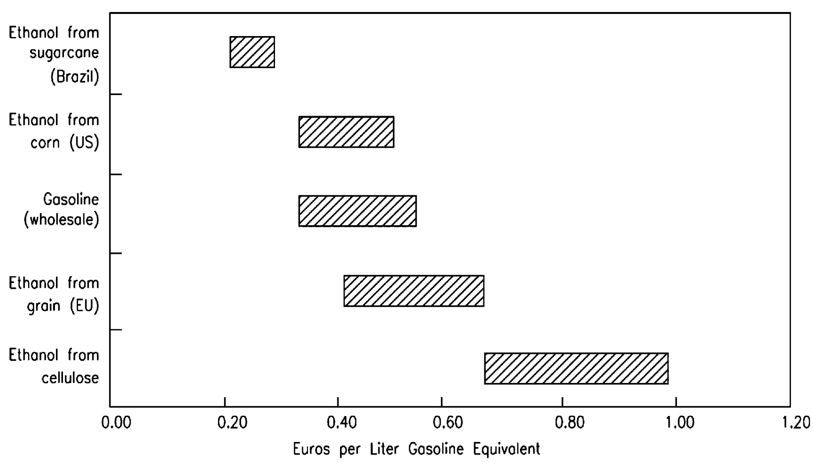

Fig. 9. Production cost range of ethanol and gasoline in the year of 2006 [51].

2.12. Biofuels and the environment

The biofuels have been seen by many people as a cleaner way to meet the energy needs in the transport sector. According to Puppán [28] their environmental benefits are shown during the combustion in the engines, given that their emissions of CO_2 correspond to the amount that was sequestrated from the atmosphere during the growth of these plants, resulting in a closed carbon cycle. Fig. 10 shows the carbon cycle for biofuels.

It is important to keep in mind that in spite of the advantages that characterize the use of biofuels, their production and end use may have serious environmental impacts such as the use of large amounts of water, the destruction of forests, the reduction in food production and the increase in soil degradation [29].

A useful tool to determine the environmental impact of the biofuels is the life cycle analysis (LCA), i.e., the evaluation of the consumption and impacts in all the stages of the life cycle of the product.

In the case of bio-ethanol, the results of the researches using LCA as an ‘integral’ tool are contradictory, given that some studies present negative impacts whereas others are more favorable. A study carried out by Blottnitz and Curran [30] presents an assessment of 47 analyses, published along the past few years, which compares bio-ethanol with a conventional fuel using LCA. Most of the analyzed studies assess the net energy necessary for the attainment of the biofuels and the emission of greenhouse gases. Although there are differences in the considerations and limits of the systems, it is possible to reach the following conclusions: (i) attaining ethanol from crops rich in sugars in tropical countries is much more feasible than from grains in temperate regions, but the precautions regarding the use and the extension of the farmland area must be taken; (ii) the attainment of ethanol through hydrolysis and fermentation of ligno-cellulosic residue must be considered.

Different indicators are used to assess the advantages that a certain type of raw material presents in relation to others. One of the used indicators is the replacement potential of fossil fuel, expressed in GJ/ha·year, which depends on the type of agricultural material used for the production of ethanol. Fig. 11 presents this comparison.

Another indicator that is used is based on the relation renewable/fossil energy (output/input) for different biofuels raw materials. It is calculated as the relation between the quantity of renewable energy attained and the quantity of fossil fuel that was consumed in the entire life cycle of production and use of biofuel per unit of product.

This indicator shows whether a fuel can be considered renewable or not. If this indicator is zero, it means that the fuel is not renewable at all and it also does not produce useful energy. If the indicator is 1, the fuel is still considered as non-renewable. An

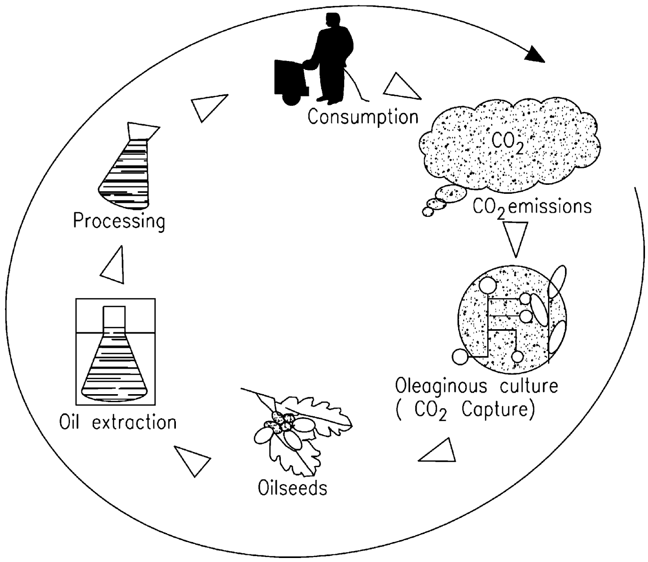

Fig. 10. Carbon closed cycle (Souto [47]).

infinite indicator shows that the fuel is absolutely renewable and any value higher than 1 shows that the fuel is renewable up to a certain point.

Pimentel and Patzek [31] show that the indicator renewable/fossil energy relation for the production of ethanol out of corn, grass and wood, which is the case of the USA, is negative, indicating that the renewable energy from ethanol out of these raw materials is lower than the energy supplied by fossil fuels during its production. A study carried out by Hill et al. [32], which considered the ethanol produced out of corn, showed a positive value for this indicator, but the value was only 1.25.

Table 5 presents the values of the renewable/fossil energy relation attained for raw materials used for the production of ethanol in different countries.

It is observed that the ethanol produced out of sugarcane in Brazil presents the best yield in case of a large-scale production in comparison with the other raw materials used in other bio-ethanol producing countries. In the future, the use of ligno-cellulosic residues for the production of bio-ethanol will probably lead to a rise in the renewable/fossil energy relation.

In relation to the environmental impact of biodiesel, there are also different results regarding the energy gain in different studies.

Pimentel and Patzek [31] present unfavorable results for the production of biodiesel out of sunflower and soybeans. The main reasons are the low agricultural yield and the high energy consumption of the process that attains the oil out of these raw materials. Wesseler [33] suggests considering in Pimentel and Patzek's study (2005), the cost of the opportunity in the processing of the raw materials. This way, it is possible to get positive energy balances.

The analyzed studies show that depending on the type of vegetable crop that will be used and the method of growth and harvest, there must be positive and negative effects on the use of the soil, quality of water, and quantity of net emission to the environment.

Table 6 presents a summary of the renewable/fossil energy relation for the biodiesel life cycle from several raw materials in different countries.

It also shows that it is possible to observe that the renewable/fossil energy relation for oil palm biodiesel is higher in comparison with the one attained for other cultures. The main reason for that is the high productivity of the oil palm, which is nearly eight times higher than the other plants. The culture of oil palm also produces a larger amount of biomass, which aggregates value to the industrial process and to the agricultural production, with the possibility of using it as fuel for steam and electricity generation.

The greatest life cycle energy consumption input fraction corresponds to the one related to the methanol used for the transesterification process, followed by the agriculture one. The replacement of methanol for sugarcane bio-ethanol will allow the attainment of values in the renewable/fossil fuel relation above 9.0 [34]. LCA studies must consider also the type of pre-existing ecosystem, the carbon balance and co-products' energy allocation.

Therefore, the selection of the appropriate type of crop for a certain region may reduce the associated environmental impact, once it is possible to reduce the need to use fertilizers, water and the pollution related to the process. Fossil fuels are used for the production of raw materials, transport and for it conversion into biofuels.

2.13. Biofuels and food security

Poverty in rural areas and the lack of programs and funding for agricultural development are the most important causes of

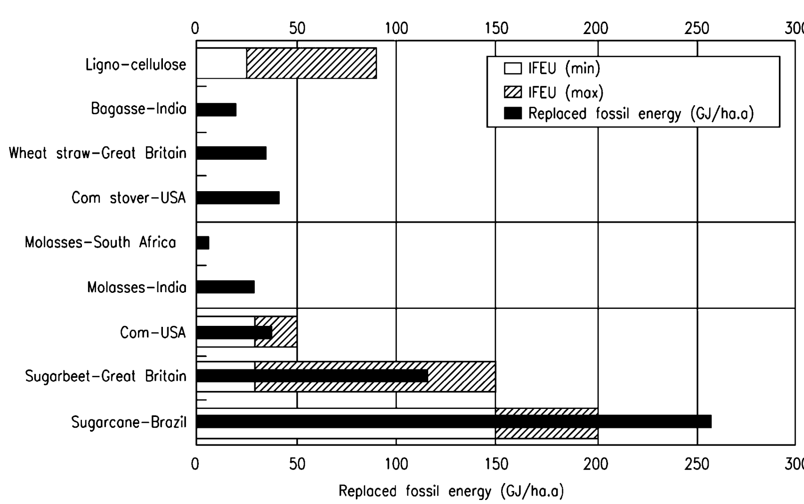

Fig. 11. Energy efficiency of bio-ethanol production out of different raw materials and in different agricultural areas of the world [30]. IFEU – Institute for Energy and Environmental Research in Heidelberg, Germany.

Table 5
Renewable/fossil energy relation for different raw materials for bio-ethanol attainment [30].

Raw material	Country	Renewable/fossil energy relation
Sugarcane	Brazil	7.9
Sugar beetroot	England	2.0
Corn	USA	1.3
Molasses	South Africa	1.1
Wheat straw	England	5.2
Corn straw	USA	5.2

Table 6
Comparison of the renewable/fossil energy relation for biodiesel attained from different oleaginous plants [34,54].

Biodiesel raw material	Country	Renewable/fossil energy relation
Rapeseed	Europe	1.7
Soybean	USA	3.2–3.4
Sunflower and rapeseed	Europe	2.4–5.23
Castor	Brazil	2–2.9
Oil palm	Brazil	4.70
Oil palm	Colombia	4.86–5.95

nourishment insecurity; conflicts, terrorism, corruption and environmental degradation also contribute significantly towards the problem [35]. Food production in the world has increased substantially. However, the insufficient household and national income, as well as natural or man-caused catastrophes have prevented the population from satisfying their basic nourishment needs.

Considering the expected population growth, which by the year 2050 must reach about 9.200 billion inhabitants [36], the problems regarding hunger and nourishment insecurity must continue or even increase dramatically in some regions (Fig. 13), unless urgent measures are taken.

In 1992, there was a meeting in Rome (World Food Summit—WFS) involving the government of 180 countries. During this meeting the countries claimed their will to reduce the number of undernourished people in the world by the year 2015 to half of the number presented in 1990. An analysis carried out ten years later showed that the results were not very satisfactory.

Within the period between 2001 and 2003 the FAO estimated a number of 854 million undernourished people in the world, out of which 820 million were in the developing countries, 25 million in the transition countries and 9 million in the industrialized countries. In 2006, in comparison with the period between 1990 and 1992 (Fig. 12), the number of undernourished people in developing countries had been reduced in 3 million. This number lies within the levels of statistic errors and does not reflect a reduction in the population that suffers from hunger and malnutrition in the world [37].

Among the causes that make it difficult to reach the goal proposed by the WFS are the armed conflicts and natural disasters. In some countries, where there are no conflicts, it is possible observe a poor agricultural and economic development together with high rates of population growth.

Fig. 13 presents data about the number of undernourished people by countries and continents within the period between 2001 and 2003.

It is possible to conclude that the undernourishment and the food security problems in the world are critical, and their relation to the production of biofuels must be studied.

The main causes of food insecurity are poverty, in terms of income, access to education, agricultural resources, technology and credit lines for food production. In most of the countries that suffer from food insecurity the most vulnerable population depend mainly of the local agriculture [38]. This way, the rural development is an important path towards the reduction in poverty and food insecurity.

Thus, countries with a better climatic and land potential for the development of biofuels have significant possibilities of developing their agricultural regions, which can improve the population's life condition substantially, by rising their income.

Within this scenario, the role of the governments to elaborate regulatory marks regarding the use and the distribution of the land is of the utmost importance, given that one of the possible disadvantages of biofuel programs may be the concentration of the land ownership, which may generate more poverty, monoculture, forest destruction, and aggravate the environmental impacts.

On the other hand, considering that the amount of land in the world available for agriculture is limited, it is necessary to define the fraction of farmland that could be used for the production of biofuels.

Cereals are the most important source of nourishment in the world [19], either for direct human consumption or indirectly, for feeding livestock. Therefore, variation in the availability and prices of cereals may be crucial for the world's food supply. The use of farmland and grains that could be consumed by humans for biofuel production is already sending warning signals in some places of the world.

The USA is responsible for 70% of the corn world export. As more and more distilleries are being built there for ethanol production, the concern in soaring up, both from the food manufacturers that depend on these grains, and for countries importing food and oil simultaneously. As the oil prices go up, the production of biofuels out of agricultural products is more profitable and, therefore, there is a risk of the price of a raw material used for biofuel production to increase beyond the price offered by the food industry, then, this raw material will be converted into fuel. In Europe, the production

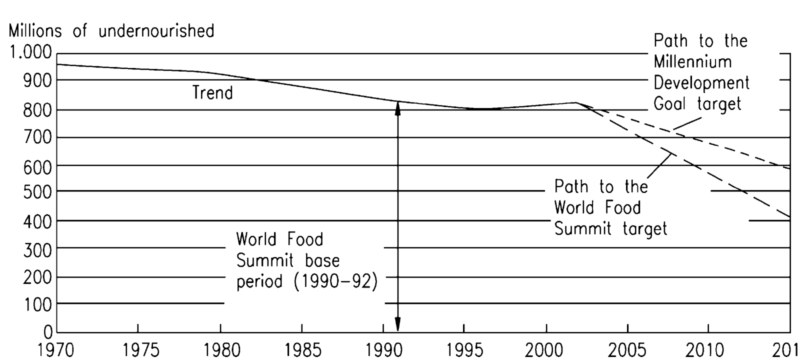

Fig. 12. Number of undernourished people in developing countries within the period between 1990 and 2002 and the projections until 2015. Source: [37].

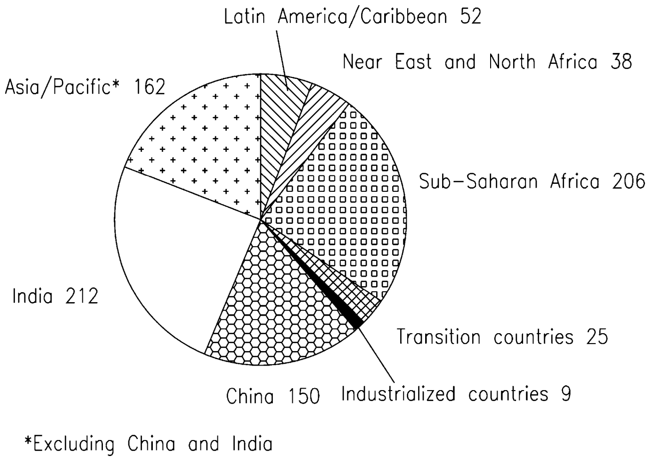

Fig. 13. Distribution by regions and countries of the total number of undernourished people in the world within the period between 2001 and 2003 [37].

of biodiesel out of vegetal oil led the margarine producers to request help for the European Parliament, given the inequality of the prices that they had to compete with the biodiesel refineries [39].

The area destined to corn crops in the USA in 2007/2008 has been the largest one since 1944 [40]. The areas used for this type of crop have been growing and pushing areas of other crops such as soybeans and wheat. As more grains are being destined to energy purposes, the inventories available for food are dropping, which causes the warnings in relation to the availability of food and the rise in the price. This way, the increase in biofuel production in the USA had a direct influence on the prices of cereals and other food products related to them [41]. In 2006, the price of wheat and corn reached the highest levels over the past 10 years.

In Mexico, there is great concern regarding the prices of corn, given that the production of tortillas, the main food of the low-income population, depends on the corn produced in the USA. Considerable rises in the prices of sugar were observed in Colombia because of the increase in ethanol production [42].

According to a report presented by Wahenga [43] "a rise in the price of food can be expected mainly because of two reasons: the high prices of agricultural productions (mainly because today agriculture is the main consumer of fossil fuels) and the influence the biofuels have on the grain world prices".

Recently, The World Food Programme (WFP) expressed its concern about the rise in the price of food over the past 5 years [44]. Among the causes said to be related to this increase are: some crops were affected by climatic conditions in some areas, reduction of the reserves of some grains such as wheat, increase in the food demand coming from India and China, rise in the oil prices and, finally, the growing use of biofuels produced out of corn and sugarcane.

In relation to this issue, UN experts state that biofuels such as ethanol can help to reduce global warming and generate jobs for poor people from rural areas, but they also warn that the benefits could be eliminated by serious environmental problems and by the rise in the food prices if the growth of the biofuel industry happen inordinately.

The creation and establishment of regulating policies that guarantee the control of the land destined to the production of biofuels and their origin are of the utmost importance, trying to avoid a larger increase in the degradation of the environment by the accelerated growth of this market. Every year 100,000 square kilometers of land lose their vegetation, are degraded or become deserts. These facts have direct consequences towards the changes in the environment and the climatic conditions of the planet [45].

Given the growing concerns of the society in relation to the impacts on the environment and food security, a series of measures are being suggested by non-governmental organizations such as WWF, European countries and governmental sectors in Brazil and Colombia.

One example is the proposal to create an ecological stamp or another certification mechanism for the companies dedicated to the production of biofuels in Brazil. This would allow an appropriate regulation regarding the growth of this sector. For only those fuels that have the environmental certification would be allowed to be commercialized in the market.

With the implementation of these measures, an appropriate regulatory mark will be established for the future growth and expansion of crops destined to the attainment of biofuels, hence reducing the environmental risks related to their production and assuring the necessary land quotes for food production.

A real Pandora Box has been opened. The food crisis is an explosive mix of the soaring up crude oil prices, driving an exponential increase in the costs and prices of fertilizers and basic food, the increasing in the standard of living of millions of people in a few developing countries. In addition there are the striking results of the global warming, which are make evident by the coincidence of severe droughts and abnormal floods, catastrophes scattered all over the world. Financial speculation, commercial barriers and the lack of policies and funds for agricultural development must be also considered. All of these things are connected and they have a negative influence over food production, making it obvious that all the evils of this Pandora Box are emerging in an endless deadly spiral that will wipe us out unless we find ways and means to save ourselves. As in the myth, hope remains.

The Crisis blew off on everybody's faces, because we were unable to foreseen the danger. The United Nations are now claiming – maybe a little too late – for solutions, but it is unavoidable to have in mind that the present situation is the result of all the above mentioned recent causes simultaneously, added to hundreds of years of unfair distribution of wealth.

So, it is obvious that to reach real and transcendental solutions to the Crisis it is necessary to transnacionalize the human solidarity by:

a) Recognizing the real causes that drove to the present situation;
b) Facing the problems with a responsible and humanistic approach;
c) Ensuring an effective and fair international collaboration to increase food production in developing countries—this is called a new "green revolution";
d) Being wise enough not to drive a confrontation between energy, food and the environment;
e) Getting an integral wisdom that overcomes selfishness and the temptations of partial and regional solutions.

But to fuel a car with biofuels obtained from grains, starving others is a cruel form of "unsustainable development" that our civilization had never seen and must be strongly regulated.

Those are the challenges, which are now up to us all to be capable to find the right track, because – unfortunately – there is neither a chance nor time to make a mistake.

3. Conclusions

$\surd$ From the whole panoramic view for the biofuels production, market and consumers showed above, it is clear that to qualify and to judge biofuels in a generic way conducts to a very notable

mistake. The possibilities for use landfarm in each country, the assessment of the food security for the population, the goals for improving air quality in the main cities and the determination of raw materials costs depends (between others factors) of local economies, regional political constraints and mainly of the level of development reached by each country. Besides, not all locations have the required environmental potential (sun radiation, soil fertilization, water supply) available at cost-based scale.

√ The 'impending' exhaustion and the oil high prices and the need to mitigate the greenhouse effect make the world tendency towards the massive use of biofuels an alternative that can join energy security with environment conservation without necessarily compromising the nourishment of the human beings. However, it is necessary to consider that biofuels will be just a partial solution for the problem regarding the availability of automotive fuel. The global solution goes through transport electrification, the production of liquid and gaseous fuels out of coal and hydrogen using renewable sources of energy, vehicles that run on solar energy, together with a radical change in our consumption habits.

√ Technological development will allow the advance from the current option, limited to biodiesel and bio-ethanol (1st generation biofuels), to cellulosic ethanol, methanol, DME and bio-hydrogen, all attained from thermo-chemical platforms and the biological conversion of ligno-cellulosic residues (2nd and 3rd generation biofuels). This will allow the use of huge amounts of raw material and the reduction of the impact on food production. More investments in R&D programs are necessary so that the technologies for the production of 2nd and 3rd generation biofuels can reach a commercial stage within a period of 10–15 years.

√ The life cycle analysis and the associated sustainability indicators constitute important tools to support decision-making processes regarding biofuel-producing programs. Contradictory results of the LCA application show the need for more severity regarding the definition of the range and geographic limits of the study.

√ The fight against hunger in the world goes through sustainable development of rural regions, which would allow the access to jobs and income for millions of people. Programs aiming at growing oleaginous plants and the production of biofuels could contribute towards this fight, mainly in degraded areas.

√ When the impact of biofuels on food security is assessed, it is important to make a distinction between their production out of cereals and sugarcane or oleaginous plants, which are not appropriate for human consumption. An international and regional analysis of the problem is mandatory in order to define whether there are local conditions to implement similar programs. On the other hand, it is necessary to consider the impact of other factors such as the high prices of oil, armed conflicts, natural disasters and soil degradation.

√ A regulatory mark and certification mechanisms that establishes the limits regarding the use of land, the environmental impacts and that would encourage the improvement of the life conditions of the rural workers involved with biofuel programs are also necessary.

√ Brazil has climatologic conditions and exceptional availability of land and water for the development of programs aiming at the production of biofuels. Another important factor is the country's experience of large-scale production, distribution and consumption of ethanol attained out of sugarcane. However, investments in R&D programs, infrastructure and an appropriate regulatory mark are still mandatory. Plantations for biofuels production must not change the today's agricultural frontiers, their areas must be expanded through a better use of the land presently used for livestock and degraded one.

√ The attainment of a by-product for livestock feeding from ethanol production out of sugarcane bagasse will mean a significant advantage for the livestock sector of the countries that produce this fuel out of this raw material, reducing the need of large extensions of land for pastures.

√ The development and use of biofuels, as an alternative of higher impact and short-term feasibility, do not ignore or disqualify the space of non-conventional energy sources such as wind, solar, geothermal and tidal energy, which still require a technological development to increase their feasibility and weight, are true alternatives that complete the scheme of a future, and a conceivable, better New World.

Acknowledgments

The authors want to express their gratitude to Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG) and Conselho Nacional de Pesquisas (CNPq) for the financial support received.

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